Institute of Nuclear Technology and Energy Systems

University of Stuttgart
Germany

TURBULENT LAGRANGE PARTICLE TRAJECTORY MODEL FOR CHANGING ATMOSPHERIC CONDITIONS

S. Haug, W. Scheuermann, E. Laurien

Knowledge Management and Numeric

MOTIVATION

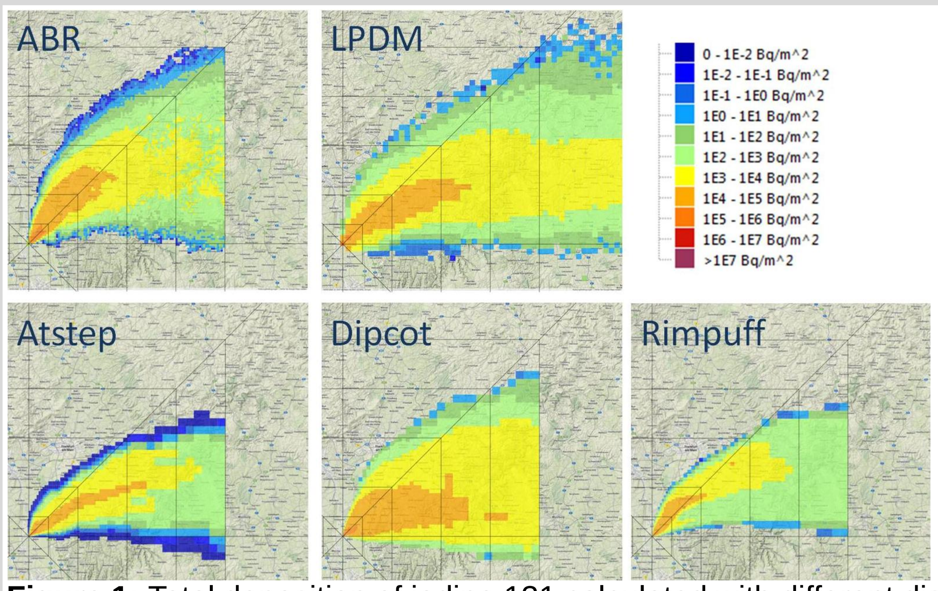


Figure 1: Total deposition of iodine 131 calculated with different dispersion models (van Arx et al, 2014)

Comparison of the particle dispersion model
- ABR developed at IKE
- Atstep, Dipcot, Rimpuff as part of jRODOS
- particle model from the German weather service LPDM

For the comparison a forecast weather situation is used.

In figure 1 simulations of the dispersion models are shown:
- ABR have a wide opened plum, especially in north-west direction
- ABR plume center follows the main wind direction with high plume spread in transverse direction

→ Differences of ABR model based on turbulence descriptions

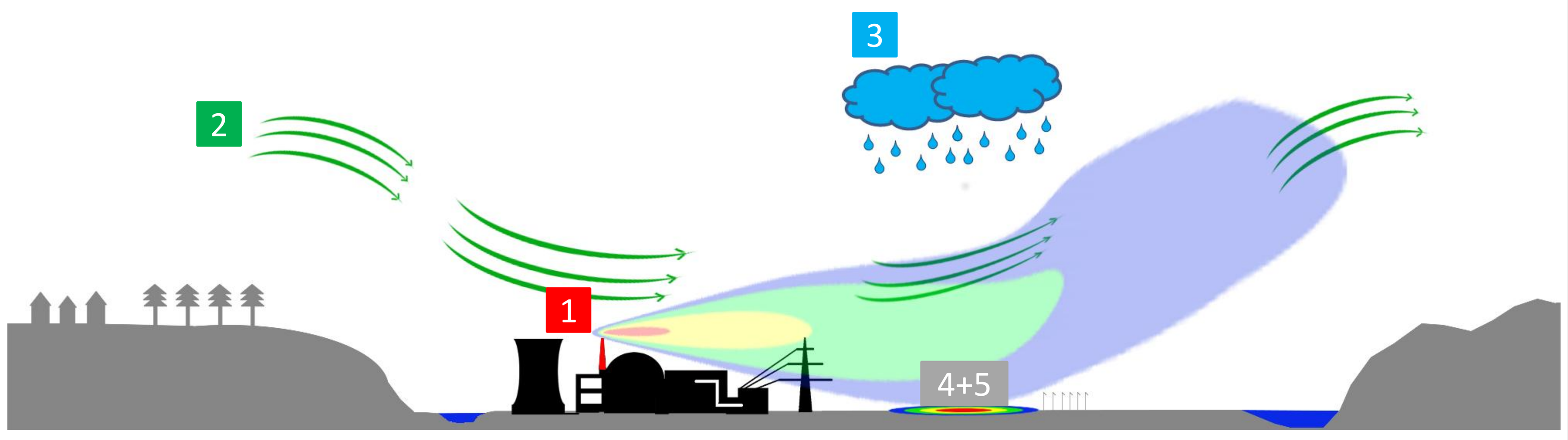
AIMS OF THIS POSTER

Discussions of turbulence models to improve the particle dispersion implemented in the ABR. Requirements of the model:

- Apply both constant and varying atmospheric conditions in space and time as influences on turbulence
- Take into account non-isotropic velocity fluctuations based on turbulent kinetic energy and Lagrange time
- Use a fast implementation for the parameters turbulent kinetic energy and Lagrange time, due to constraints of emergency management

ABR-SYSTEM

1. Release calculation regarding current fuel loading and nuclear decay for time since SCRAM
2. Wind field generator including topographic influences and atmospheric stability
3. Lagrange particle model with dry and wet deposition of the particle as well as precipitation
4. Cloud-shine computation with adjoint fluxes by splitting the energy spectra of the nuclides
5. Dose rate estimation from ground shine, inhalation and thyroid impact



Particle-in-cell method:
- Dispersion particle trajectory model with concentration evaluation by counting particles in each grid cell (Chino et al, 1991)
- Mean wind speed calculated by wind field generator
- Turbulence model based on Gaussian distribution for constant atmospheric conditions
- Diffusion magnitude evaluated by different experiments
- Experimental plume dispersion parameter from Pasquill-Gifford and Karlsruhe-Jülich used for turbulence prediction
- Dispersion parameter depend on stability class, source height and source distance

POSSIBLE NEW TURBULENCE MODELS

Random-walk method:
- Turbulence description for constant and varying atmospheric conditions in three directions introduced by Smith, F. B. (1968)

$$u_i'(t+\Delta t) = R_i(\Delta t)\cdot u_i'(t) + k_i \cdot \left(1 - R_i^2(\Delta t)\right)^{0.5} \cdot \eta(t) \quad ; \quad i = x, y, z$$

- The model consists of two parts: a correlated part for fluctuation history and an uncorrelated purely statistical part
- Influencing proportion on each term is the autocorrelation function $R_i(\Delta t) = \exp(-\Delta t / T_L)$ proposed by Taylor, G. I. (1921)
- Turbulence model regards anisotropic kinetic energy k_i and Lagrange time T_L
- Uncorrelated part biased with Gaussian random number η with zero mean and variance 1

Lagrange time models:
- Lagrange time description introduced by Hanna, S. R. (1981)
- Calculation related on mixing height h_{mix} , which regards the stratification of the atmosphere
- Lagrange time influenced by kinetic energy k_i; fast eddies → small eddy life time
- Monin-Obukhov length L regards heat influences and the stability of the atmosphere
- Mean velocity $\bar{u}$ taken into account

Turbulent kinetic energy models

Similarity theories
- Anisotropic turbulence k_i expressed by friction velocity u_*, Monin-Obukhov length L and roughness z_0
- Planetary boundary layer thickness ignored → validated for unstable and convective atmospheric conditions

Boundary-layer parameterization by van Ulden, A. P. and A. A. M. Holtslag, (1985)
- Parameterization for surface stress and heat flux → Richardson number can be calculated
- Turbulence calculation by u_*, mixing height h_{mix} and particle height z

Turbulence description used by AERMOD atmospheric dispersion modeling system
- Turbulence description divided into two influencing parts: Turbulence based on shear stresses and turbulence influenced by thermal heating (de Visscher, A. 2013)
- Shear and heat influences in Prandtl layer; heat influences only in Ekman layer
- Turbulence model regards mixing height h_{mix} and convective velocity w_*

MODEL COMPARISON

Particle-in-cell method:
- ✓ Fast running turbulence model with a stable numerical process
- ✓ Only a few parameters are necessary to run
- ✓ All input parameters are easy to provide

- ❖ Only stochastically model
- ❖ Turbulence description defined by the six Pasquill stability classes
- ❖ Experimental plume parameter depend on source height or source distance
- ❖ Constant conditions assumed for parameter evaluation; varying condition during simulation
- ❖ Experimental parameter only derived for a plume expansion of 10 km

Random-walk method:
- ✓ Turbulence descripted as a two parameter problem of time and kinetic energy
- ✓ Previous turbulence processes are considered
- ✓ A continues turbulence description is used
- ✓ Varying space and time influences are regarded
- ✓ Turbulence description is a function of atmospheric conditions, not a function of travel time

- ❖ Input parameter have to be provided on a fine model grid
- ❖ Different models have to be implemented and compared with each other
- ❖ Validation and model evaluations have to be set up

CONCLUSION

- Improvements to take into account varying atmospheric conditions have to be implemented
- Nevertheless time-restrictions should be in focus for civil protection headed before scientific numerical effort

FUNDING

Baden-Württemberg

Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg

REFERENCES

van Arx, C., L. Brücher, V. de Donno, B. Gerich, H. Glaab, C. Grimm, R. Martens, J. Päsler-Sauer, W. Scheuermann, Horst S., P. Schumacher, H. Walter, S. Weimer and T. Wilbois 2014: Comparison of operational atmospheric dispersion models in Germany, 16th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, H16-149

Chino, M., H. Yamazawa, H. Ishikawa 1991: Utilization of some numerical models for emergency response against nuclear accident, Nuclear Energy Agency of the OECD (NEA), Paris, Vol. 75, 198–207

Hanna, S. R. 1981: Lagrangian and eulerian time-scale relations in daytime boundary layer, J. Appl. Meteorology, Vol. 20, 242–249

Smith, F.B. 1968: Conditioned particle motion in a homogeneous turbulent field, Atmospheric Environment, Vol. 2, Issue 5, 497–508

Taylor, G. I. 1921: Diffusion by continuous movements, Proceedings of the London Mathematical Society, No. 20, 196–211

van Ulden, A. P. and A. A. M. Holtslag, 1985: Estimation of atmospheric boundary layer parameters for diffusion applications, J. Climate Appl. Meteor., 24, 1196–1207

de Visscher, A. 2013: Air dispersion modeling: Foundations and applications, Wiley, New Jersey